

# Flow Through the Straits of the Philippine Archipelago Simulated by Global HYCOM and EAS NCOM

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## LONG-TERM GOALS

We plan to collaborate with other DRI participants to better evaluate and understand the dynamics seen in observations and model results within the Philippine Archipelago, a strategic region with numerous straits. The model results will come from the  $.08^\circ$  and  $.04^\circ$  global HYbrid Coordinate Ocean Model (HYCOM) and a  $.088^\circ$  East Asian Seas (EAS) Navy Coastal Ocean Model (NCOM), the  $.04^\circ$  global HYCOM and some finer nests starting in FY09, the others from the outset.

## OBJECTIVES

Objectives for our DRI participation are (1) high resolution simulations (with and without tides; with and without data assimilation) which provide a larger scale context for the observations, (2) model-data comparisons with the measurements, (3) studies of observational representativeness in measuring transports through straits, (4) investigation of non-tidal and tidal (barotropic and internal) influences on specific sub-regions of interest, especially where measurements are available, and (5) provide boundary conditions for nested models.

## APPROACH

*Ocean models:* HYCOM: Traditional ocean models use a single coordinate type to represent the vertical, but no single approach is optimal for the global ocean. Isopycnal (density tracking) layers are best in the deep stratified ocean, z-levels (constant fixed depths) provide high vertical resolution in the mixed layer, and  $\sigma$ -levels (terrain-following) are often the best choice in coastal regions. The generalized vertical coordinate in HYCOM allows a combination of all three types (and others), and it dynamically chooses the optimal distribution at every time step via the layered continuity equation.

NCOM uses  $\sigma$ -levels when the depth is shallower than 137 m and z-levels, optionally with partial cell topography, elsewhere.

Both models use a C-grid, have scalable, portable computer codes that run efficiently on available DoD High Performance Computing (HPC) platforms, and have a data assimilation capability. NCOM runs with tides. These will be added to HYCOM in the future.

*Task (1) (corresponding to the list in the objectives) High resolution ocean model simulations:*

HYCOM will be run globally with  $.08^\circ$  (9 km equatorial) and  $.04^\circ$  (4 km equatorial) resolution, the latter starting in FY09. These will be run largely under the sponsorship of partnering and related projects (see Related Projects below). The simulations will be run with high frequency climatological forcing and will be run interannually at least over the time frame of the International Nusantara STratification ANd Transport (INSTANT) and DRI data sets. Simulations will be run with and without tides, and with and without data assimilation.

The  $.088^\circ$  EAS NCOM ( $17^\circ\text{S}$ - $52^\circ\text{N}$ ,  $98^\circ\text{E}$ - $158^\circ\text{E}$ ) has been running in real-time with tides and data assimilation since October, 2003. It receives boundary conditions from  $.176^\circ$  (20 km) equatorial resolution global NCOM (with data assimilation but no tides).

Nested models of the Philippine Seas using HYCOM and NCOM are also planned. Both models already have a robust nesting capability. During the first 3 years the nests would have 3 km resolution and during years 3-5 a Philippine Seas nest in  $.04^\circ$  global HYCOM would have 1.5 km resolution. The nested models will be very useful (1) for investigating the impact of resolution on other aspects of the simulations, (2) as boundary conditions for even higher resolution nested models of Philippine Seas subregions run by other DRI participants, and (3) for data representativeness studies. Even same resolution nests will be useful in studying the impacts of tides, different vertical mixing schemes and parameter choices, and data assimilation on other aspects of the Philippine Seas circulation.

*Task (2) Model-data comparison studies:* The model-data comparisons will be used to evaluate and improve the models and to help interpret the data. Data that resolve tidal frequencies, and measure straits transports, the vertical structure of the water column, and the nature of its variability will be particularly useful. Measures of year-long means and seasonal variability will also be valuable. Model output will be archived at measurement locations with sufficient temporal resolution for tides. Measurements used in conjunction with models will be vital in studying the roles that tides and other processes play in determining transports through straits and the vertical structure of the water column. Timely access to DRI data will greatly facilitate this process and opportunities for joint publications with other DRI participants are highly desirable, particularly in years 3-5.

*Task (3) Studies of data representativeness:* All of the models listed in Task (1) can be very useful in assessing the ability of DRI observational arrays to measure integral properties, such as straits transport (both in terms of spatial coverage and length of record), particularly if they perform well in the model-data comparisons (Task 2). They can also be used in estimating appropriate corrections. Doing this using a suite of model simulations, rather than just one, and picking models that best match the data should improve the quality of corrections and enhance confidence in the results.

*Task (4) Study the interaction of tidal and non-tidal processes in subregions of DRI interest:* The Philippine Seas form a region where large amplitude external and internal tides may have a significant impact on the non-tidal circulation and water mass structure. We are particularly interested in collaborative studies and joint publications on related topics with other DRI participants in subregions of DRI interest.

*Task (5) Provide boundary conditions for nested models of other DRI participants:* HYCOM and NCOM will be used to provide boundary conditions to nested models of other DRI participants. The boundary conditions can have resolution as fine as 3 km during years 1 and 2 and as fine as 1 km during years 3-5. Advance coordination would be needed to make sure the required time period was archived at the temporal resolution and locations needed. We are also interested in model inter-comparisons to investigate the impact of model resolution and design on the simulation of processes in the vicinity of straits.

## WORK COMPLETED

With regard to objective (1), output from .08° global HYCOM and .088° EAS NCOM has been used to aid mission planning for the June-July 2007 Exploratory and subsequent DRI cruises. Before the Exploratory cruise began, results from non-assimilative climatologically-forced and assimilative interannually-forced simulations of the Philippine Seas were forwarded to the observational team with emphasis on straits where intensive sampling was planned (see Figure 1 for an example). These included cross-sections of the temperature, salinity and velocity as well as time series of transport through the inflow and outflow straits. Before the Exploratory cruise commenced, output from both real-time systems was posted on the NRL webpages for guidance and that continued for the duration of the cruise.

Regarding objective (5), boundary conditions from the real-time data assimilative .08° global HYCOM system were extracted and provided to the Rutgers group running the Regional Ocean Modeling System (ROMS). These included hindcasts five days in arrears, the nowcast and then up to a four day forecast. In addition, atmospheric forcing (wind stress, heat fluxes and precipitation) from the 0.5° Navy Operational Global Atmospheric Prediction System (NOGAPS) was provided. These are the same forcing fields used by global HYCOM.

A .08° Indonesian Seas version of HYCOM encompassing the region 98°-135°E, 15°S-25°N and nested within .08° global HYCOM was set up and some preliminary simulations were performed. These focused on the mechanics of the nesting and helped determine optimal updating frequency between the outer and inner models.

Work began implementing and running the NRL Relocatable (RELO) NCOM in the Philippines Sea region. The RELO system is a version of NCOM designed to be quickly set up and run in any region. An initial test used a triple nest setup with an outer 8 km nest covering the region 116°-126.5° E and 1°-16° N. Boundary conditions are obtained from EAS NCOM which includes tides. Two smaller nests (with ~2.5 km resolution) focused on the Mindoro and Surigao Straits. All tests were run with NOGAPS 0.5° forcing and did not include data assimilation.

## RESULTS

Because knowledge of the Philippine Seas physical oceanography and associated straits is rather limited, simulated output of the vertical structure of the water column was useful to the team planning the Exploratory and subsequent cruises. While there were some differences, the general flow pattern was similar between HYCOM and NCOM in Mindoro Strait with net southward flow from the South China Sea into the Sulu Sea. Larger differences were noted in Surigao Strait that may be related to differences in the model topography and coastline geometry, but the overall representation of net

Pacific Ocean flow westward into the Bohol Sea was consistent between the models. The multi-year time series of transport were useful because they provided the seasonal cycle across the inflow/outflow straits and allowed the observational team to adjust and fine-tune their cruise plan accordingly.

Real-time output posted on the web was also very useful to the observational team. During the first week of the Exploratory cruise, chief cruise scientist Arnold Gordon noted in the first weekly report that the hull-mounted ADCP data showed northward flow in the upper 150 m of Mindoro Strait and southward flow below 200 m, a result consistent with both the HYCOM and NCOM velocity sections pulled off the web. In the last cruise report, Gordon reported an increase in the northward upper 100 m flow in Mindoro Strait from 10-20 cm/s in early June to 30-50 cm/s in late June; this was also simulated by real-time global HYCOM and NCOM (Figure 2). While not perfect, he noted that the simulated results were encouraging and exceeded expectations. This is just one example of simulated output being compared to the real-time data sampled during the cruise.

Boundary conditions from real-time assimilative global HYCOM and atmospheric forcing from NOGAPS were successfully used to force regional Philippine Seas version of ROMS with 5 km resolution. The Rutgers group was appreciative of the boundary forcing provided by HYCOM.

Initial triple nest testing of RELO NCOM has been performed to determine the optimal setup for the region. By default, the RELO system extracts a topography based on NRL DBDB2 and this product proved to be inadequate for this region without additional hand-editing. A test is underway using bathymetry consistent with EAS NCOM as that topography has been hand-edited to more accurately depict the coastlines and depths. Initial testing has also indicated stronger currents with finer horizontal grid resolution. Future tests will include finer resolution atmospheric forcing (COAMPS) and possibly data assimilation. RELO NCOM is designed to assimilate all available data (altimetry, profile data, moorings, satellite SST).

## **IMPACT/APPLICATIONS**

Output from  $.08^\circ$  global HYCOM and  $.088^\circ$  EAS NCOM has been used to provide the larger scale context of the circulation in the Philippines Seas. Because so little is known of the oceanography in this region, it was used as guidance by the team designing the Exploratory Cruise. In addition real-time output from data-assimilative  $.08^\circ$  global HYCOM was used as boundary conditions for a real-time regional ROMS run by the group at Rutgers.

## **TRANSITIONS**

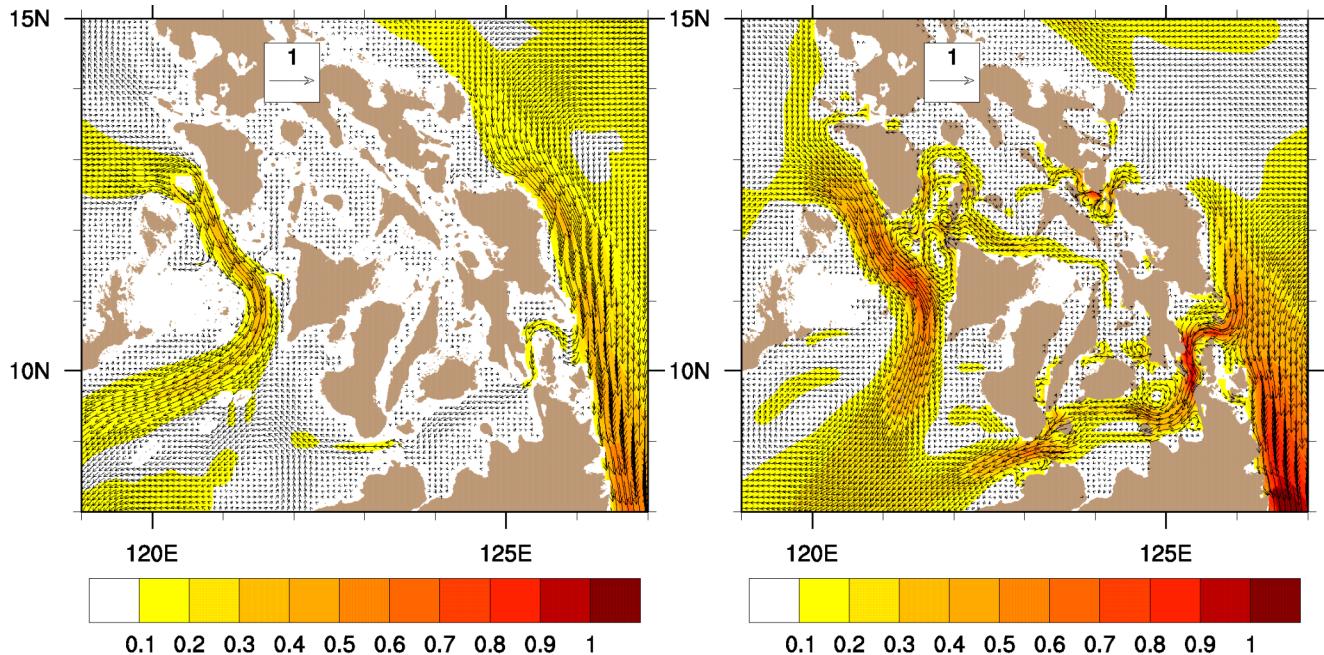
Global NCOM is operational at NAVOCEANO while EAS NCOM and  $.08^\circ$  global HYCOM are pre-operational and running in real time. EAS NCOM is waiting for OPTEST to be completed, while global HYCOM will be transitioned to NAVOCEANO by the end of calendar year 2007 and will be OPTEST'ed in 2008. The latter has 6.4 funding (see below) for evaluation/validation.

## **RELATED PROJECTS**

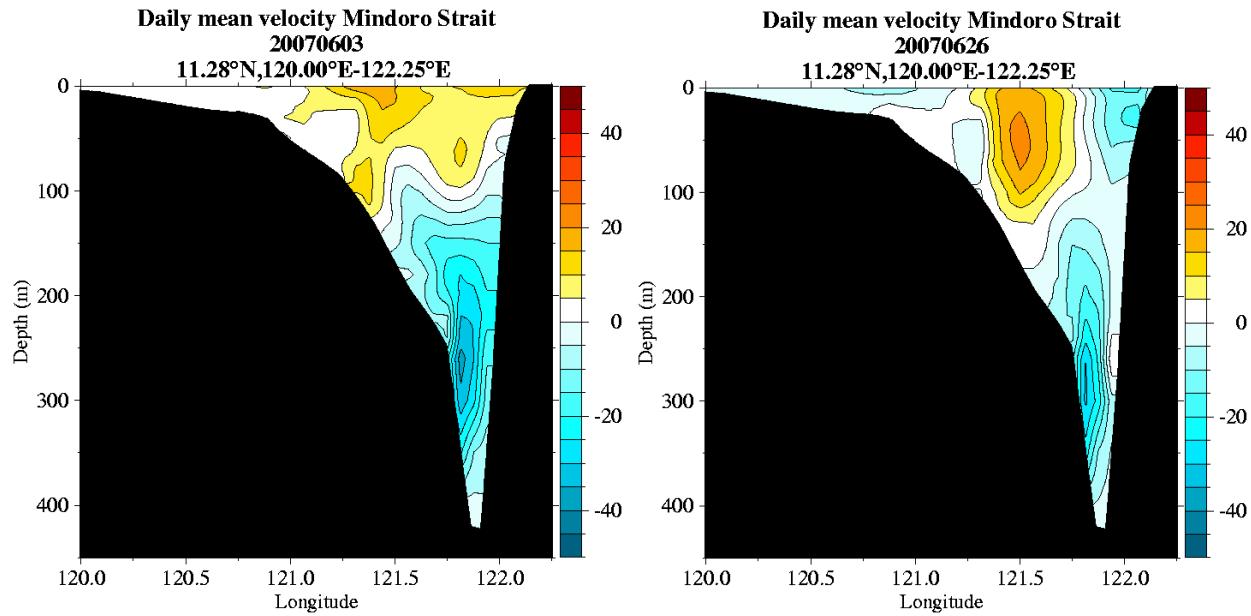
As partnering funding, we would support related Indonesian/Philippines Seas work using two existing 6.1 NRL Base projects: "Global remote littoral forcing via deep water pathways" (H. Hurlburt, PI) and "Dynamics of the Indonesian throughflow (ITF) and its remote impact" (E.J. Metzger, PI). Related

projects supporting global HYCOM would also substantially benefit this DRI project. These include the multi-institutional effort to develop a next generation eddy-resolving global ocean prediction system using HYCOM. This effort is supported by the FY04-08 NOPP project, “U.S. GODAE: Global Ocean Prediction with the HYbrid Coordinate Ocean Model (HYCOM)” (<http://www.hycom.org>) (H. Hurlburt, NRL PI) and related existing 6.4 projects “Large Scale Prediction” (E.J. Metzger, PI).

The computational effort will be strongly supported by DoD HPC Challenge and non-challenge grants of computer time. At present  $.08^\circ$  global HYCOM is running under an existing FY05-08 DoD HPC Challenge grant and will be run mainly or entirely without tides. The nested models will run under NRL grants of non-challenge HPC time. The  $.08^\circ$  global HYCOM is very computationally expensive to run, but the available computer power increases every year and we will be able to run a limited number of  $.08^\circ$  global HYCOM simulations including tides with NRL non-challenge HPC time. We plan to propose for an FY09-11 DoD HPC Challenge grant to run  $.04^\circ$  global HYCOM, mainly with tides but at first without data assimilation.



**Figure 1:** Simulated mean 2004 ocean currents (vectors) overlaid on speed (color filled with darker colors indicating higher speeds) at 25 m depth for the seas in and around the central Philippines for (left) data-assimilative  $1/12^\circ$  global HYCOM/NCODA and (right)  $1/16^\circ$  EAS NCOM with tides. The reference vector (top center of each panel) shows the length of a 1 m/s ocean current. Areas with no vectors are either model land or are shallower than 25 m.



**Figure 2: Daily mean north-south velocity (cm/s) from the surface to 400 m depth in 1/16° EAS NCOM through Mindoro Strait (11.3°N, 120.0°-122.25°E) that connects the South China Sea and the Sulu Sea at (left) 3 June 2007 and (right) 26 June 2007. Yellow/orange/red colors indicate northward flow while blues indicate southward flow; darker colors designate higher velocity.**